

Planar Edgeless Silicon Detectors for the TOTEM Experiment

G. Ruggiero^{a,*}, E. Alagoz^a, V. Avati^b, K. Eggert^a, I. Eremin^c, N. Egorov^d, H. Niewiadomski^a, E. Noschis^a, M. Oriunno^a, A. Sidorov^d, W. Snoeys^a.

^aCERN, CH-1211 Geneva, Switzerland

^bHelsinki University, Helsinki, Finland.

^cMegaimpulse / Ioffe Physico-Technical Institute of Russian Academy of Sciences, St.Petersburg, Russia

^dResearch Institute of Material Science and Technology, Zelenograd, Moscow, Russia

Introduction

The TOTEM experiment will detect LHC leading protons at special beam pipe insertions, the Roman Pots. The detectors inserted in the Roman Pots have to fulfil stringent requirements set by the machine and the TOTEM experiment [1]. During operation the detector edge is positioned at a distance of less than 1 mm from the axis of the high intensity proton beam where a 200 μm window separates the detectors from the primary beam vacuum. For optimal performance, the detector has to approach the 10 σ envelope of the beam as close as possible. Consequently, the detectors should be active up to their physical edge. It is our aim that they are edgeless to a level of about 50 μm .

In general, planar Silicon detectors have a wide (0.5 – 1 mm) insensitive border region around the sensitive area. This insensitive region is occupied by a sequence of guard rings which controls the potential distribution between the detector's sensitive area and the die cut to minimize the electrical field and thus the surface leakage current. In this paper a new approach on how to reduce this region will be described.

Conception and Thermo-Electric Characterization

The conceptual idea of the new approach is to apply the full detector bias across the detector chip cut and collect the resulting leakage current on an outer ring, which surrounds the active area and which is biased at the same potential as the detecting strips (see Fig. 1). This ring is separated from the detector biasing electrode (the strips are biased by means of a punch-through structure between this biasing electrode and the strips). Separating this ring from the bias ring strongly reduces the influence of the current generated at detector edge on the active detector area. Note that the biasing electrode can be a second ring around the active area, as illustrated in fig. 1, but it can also be an electrode which is located at one side of the active area, as long as it provides a punch-through structure for every active strip. The biasing ring also acts as “clean-up ring” collecting the surface current that diffuses into the active region. In contrast with the other ring structure which provides voltage termination, this structure terminates the current, and therefore we have called it “Current Terminating Structure” (CTS).

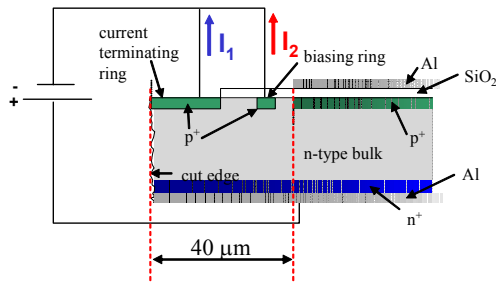


Fig1 Simplified cross-section of the detector with sensitive edge at the left side and biasing scheme

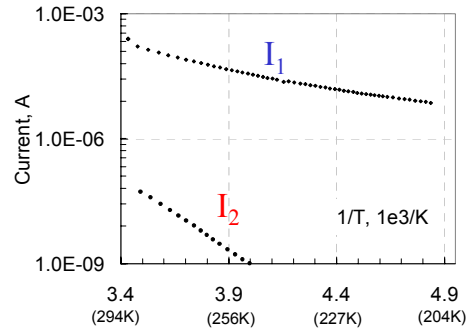


Fig2 Current-Temperature characteristics for currents drawn by the current terminating ring I_1 and the biasing ring I_2 , with the detector biased with 100 V.

The first silicon detectors produced with this CTS have been developed within a joint effort between the TOTEM group at CERN and the Megaimpulse, a spin-off company from the Ioffe PT Institute in St.Petersburg (RUSSIA). The simplified cross-section of detectors with the current terminating structures at the sensitive edge together with biasing schematics is presented in Fig. 1a. The extension of this region can be reduced to 40 μm .

Microstrip detectors of 1cmx1cm have been processed on a very high resistivity N-type silicon wafer ($\sim 8 \text{ Kohm cm}$), 350 μm thick. This set of detectors depletes fully at a reverse bias of around 20 V and were shown to be stable for biases higher than 200 V. Fig. 1b shows – for a reverse bias of 100V - the measured currents drawn by the current terminating ring (I_1) and the biasing ring (I_2) as a function of temperature.

*Corresponding author: Gennaro Ruggiero, CERN, PH Department, CH-1211 Geneva 23, Switzerland
e-mail: gennaro.ruggiero@cern.ch

I2 is 4 orders of magnitude lower than I1, which demonstrates that practically the full surface current is absorbed by the outer current terminating ring. It is worth noting that the well-known exponential temperature dependence of the reverse current of a p-n junction due to the thermal excitation mechanism of electrons transferring from valence to conduction band does not apply to the surface current. Nevertheless the reduction of the surface current with temperature is still possible and to halve this current component is sufficient to cool down at -20°C.

Test Beam Results

Silicon detectors with the CTS have been tested in September 2003 with a muon beam in the X5 area at CERN. Two test detectors (TD) were mounted on a side of a board, with the cut edges facing each other and being parallel (see fig. 3). The detectors were aligned under a microscope and the mechanical distance between the detectors was measured within a precision of better than 10 micron.

A reference detector (RD) was mounted on the back side of the board with the strip direction perpendicular to the ones of the test detectors, i.e. parallel to the sensitive edges of the two TD's. Thus, due to the high spatial resolution of the RD (strip pitch of 50 micron), the insensitive distance between the two TD's can be measured precisely and can be compared with the mechanical distance enabling a precise determination of the efficiency drop at the edges of the test detectors.

The silicon devices were coupled with the electronics foreseen for the roman pot detectors in the TOTEM experiment, i.e. the APV25 chip [2], developed within the CMS collaboration [3] for the readout of the tracker. All the detectors were operated over-depleted, with a bias voltage above 110 V. The measurements were performed at room temperature. The detectors were triggered by a 10x10 mm² scintillation counter, placed 2 m away from the detectors ahead on the beam line.

Tracks were defined by the two reference detectors RD's in coincidence either with the two left or with the two right test detectors. The schematic of the experiment is shown in Fig.3. The distribution of the hits in one reference detector conditioned by the hit also in one of the two test detectors mounted on the other side is plotted in Fig. 4. The end of the strips at the cut edge of each detector was measured with micrometric precision (~10 micron) with respect to the 50 micron strip of the corresponding reference detector. The dashed lines in the plot give the position of the strip ends that are 40µm away from the cut. Fitting the profile of the hits at the edges to evaluate the beginning of the sensitive area in the two TD's we have a discrepancy of few microns with the distance measured with metrology.

In principle with good statistics, these edges can be determined with high precision from the distributions in Fig. 4. We estimate a combined statistical and systematic error of 20 micron. Since the strips start 40 micron away from the physical edge the detectors exhibit an insensitive edge region of maximum 60 microns.

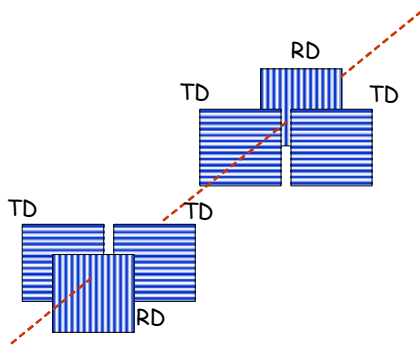


Fig.3 Arrangement of test detectors (TD) and their reference detectors (RD) with respect to the beam direction (dashed line).

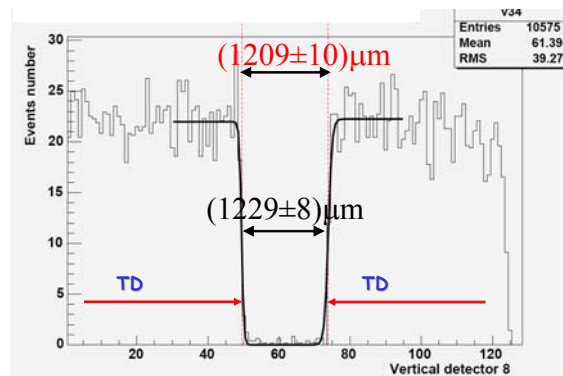


Fig. 4 Distribution of hits in the reference detector in coincidence with hits in the two test detectors. Their fit is compared to the beginning of the sensitive area of the two TD's (dashed line).

In conclusion, detectors with a current terminating structure which allows a very narrow insensitive region near the die cut were successfully tested with the CMS read-out via the APV25 chip. They showed an excellent and stable performance at room temperature with an insensitive border of less than 60 micron.

References

- [1] TOTEM TDR, CERN-LHCC-2004-002, TOTEM-TDR-001, 7 January 2004
- [2] L. Jones. "APV25-S1 User Guide Version 2.2" http://hep.ucsb.edu/people/affolder/User_Guide_2.2.pdf
- [3] The CMS Technical Proposal. CERN/LHCC 94-38, LHCC/P1 (1994)